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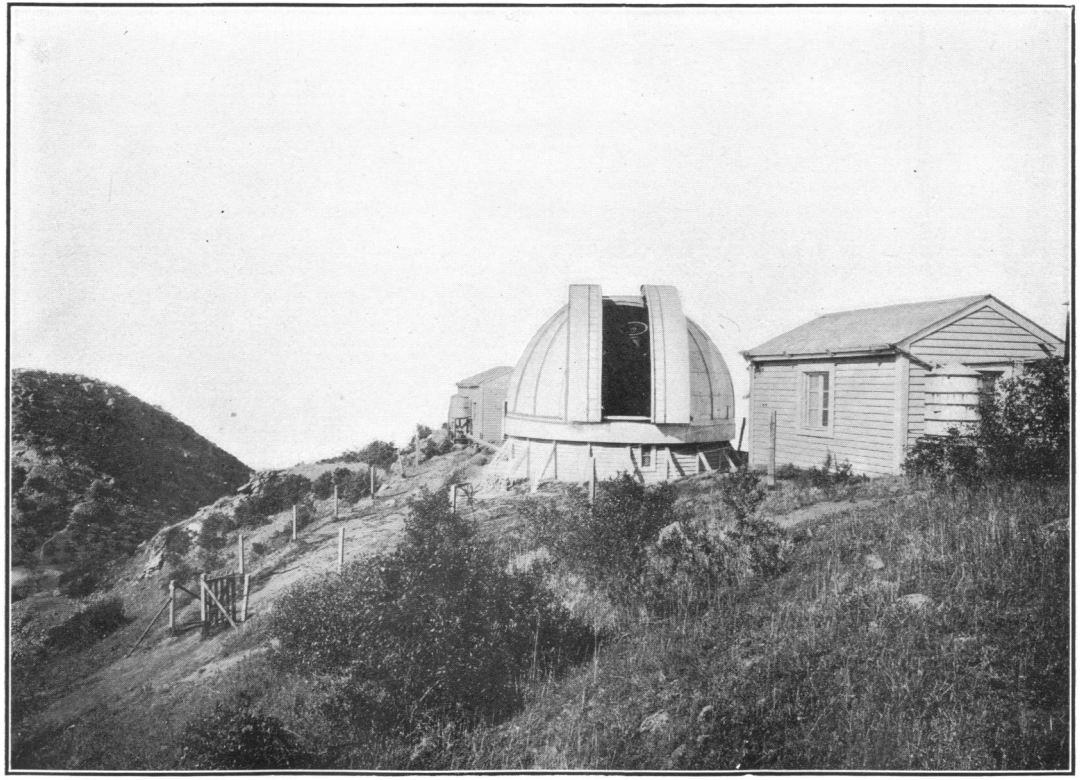

THE OBSERVATORY OF THE D. O. MILLS EXPEDITION, FROM THE NORTHEAST.

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RECENT CHANGES AT THE OBSERVATORY OF THE D. O. MILLS EXPEDITION.

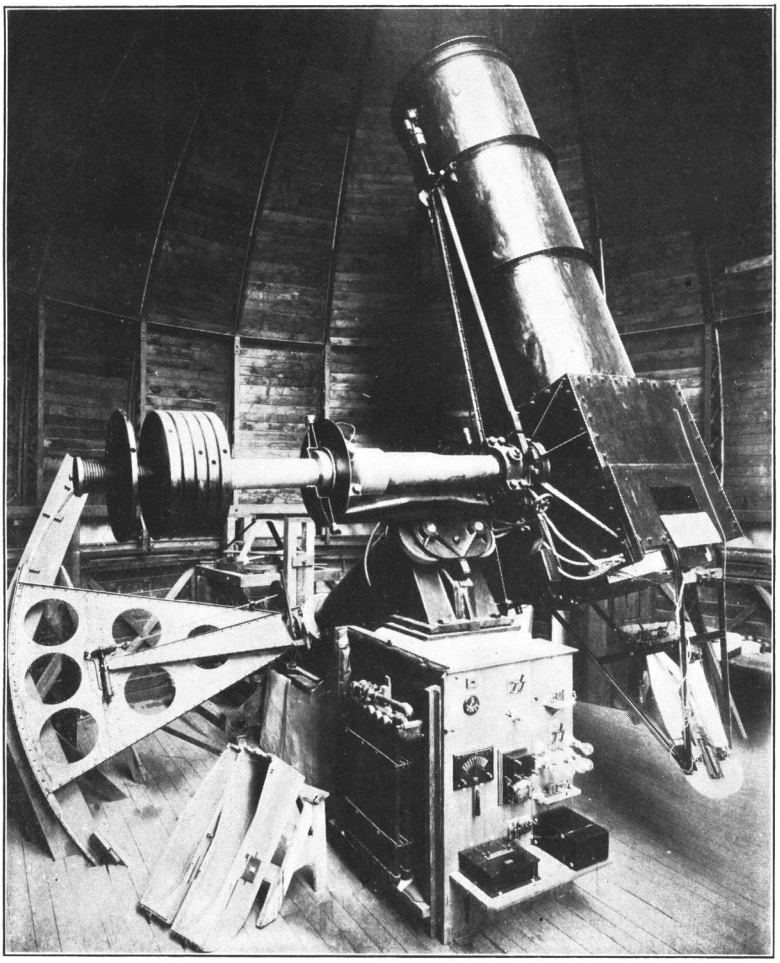
BY HEBER D. CURTIS.

When Mr. MILLS provided for a continuation of the work of the D. O. Mills Expedition to the Southern Hemisphere for five years a number of improvements in, and additions to, the equipment were decided upon by Director CAMPBELL, many of which had been suggested as desirable by the experience of Professor W. H. WRIGHT and Dr. H. K. PALMER during the course of their two-year period of work in Chile. It is the purpose of this paper to describe a number of the changes in the equipment which have been made since March, 1906, the date when Professor WRIGHT returned to the United States, and the writer assumed charge of the station. Many of the minor improvements are not of such magnitude in themselves as to warrant extended notice; but if one takes into account the difficulty of accomplishment of all such alterations and additions on a hilltop not too easy of access, in a distant country, and without skilled labor, it can easily be realized that they have cost considerable effort. Mr. GEORGE F. PADDOCK, formerly Fellow at the Leander McCormick Observatory of the University of Virginia, arrived in Santiago on August 2, 1906, and has taken an active part in the installation of all improvements made since that time.

A small building, about fourteen by seventeen feet, was first built, about thirty feet to the south of the observatory dome. It contains a workshop and two small sleeping-rooms for the observers. The observatory is located 860 feet above the city and about one mile distant from the homes of the observers. This daily or nightly climb is a matter of much less bodily strain than would be thought,—after one is well hardened to it,—but there is no change which has contributed more to

the comfort of the observers than the ability to be able to "turn in" immediately after a night's work. In the workshop have been placed a 12-inch Star engine-lathe of the new heavy model made by this company, a grinder-head, a work-bench, and an extensive collection of small tools, as well as a refrigerating machine, to which reference will be made later. The machinery is driven by a one-horsepower electric motor fastened near the ceiling. The electric line from the city to the observatory was in part rebuilt and extended to connect with the circuit of the city's lighting system, and wires were also strung for telephone communication between the observatory and the writer's home at the foot of the hill.

Professor WRIGHT had found the motion of the 37-inch reflector in declination a very difficult one. The axis was of steel, finely ground at the bearing surfaces, and running in babbitt, but such was the weight of the moving parts (about two tons) that much effort was necessary to set the telescope moving in this component. The force required to start the motion averaged fifty to one hundred pounds on the end of a 6.1-foot lever, depending upon the hour-angle of the telescope. After consultation with the makers of the mounting, designs were drawn for roller bearings in each of the declination pillow-blocks, and a ball thrust bearing at the block farthest from the telescope-tube, lack of space preventing its use at the bearing nearest the tube. The new bearings are of the frictionless type manufactured by the Anti-Friction Roller Bearing Company, of Los Angeles. As this company did not have the facilities for making such large bearings as were required in this case, free use of their patent was courteously granted by them to the makers of the mounting, the Fulton Engine Works, of Los Angeles, for the construction of the roller bearings for the Mills reflector. The system for each bearing consists of tool-steel carrying-rolls three fourths of an inch in diameter, with an equal number of alternating smaller rolls, whose only function is to obviate the sliding friction between the larger carrying-rolls. There being nothing but rolling contacts, no lubricant is necessary. Steel rings one fourth of an inch square, fitting into grooves at each end of the rolls, are screwed to the axis, and, with similar holding rings outside the roller group fitting in the same grooves, serve not only to prevent end-motion in the



THE MILLS TELESCOPE, WITH THE THREE-PRISM SPECTROGRAPH.

rolls, but to keep the smaller intermediate rolls in their correct positions. The rolls are eight inches long on the inboard, and five and a half inches on the outboard bearing. For the thrust a strong tool-steel sleeve was made to fit over the declination axis and a tool-steel bearing-ring provided to fit into a shallow recess in the outboard bearing. Between the two steel surfaces there moves freely a bronze ring pierced with seventy-two apertures, each of which contains a half-inch steel ball. The actual work of boring out the heavy bearing-blocks from six and a half to eight inches diameter and recessing the outer block for the thrust-ring was done on the observatory's lathe. The results have proved very satisfactory, the ease of motion being remarkable. It now takes, at a distance of 6.1 feet from the center of motion, but six to nine pounds to start and maintain the motion in declination at all ordinary hour-angles, and only sixteen to nineteen pounds in the extreme case when the telescope is at six hours hour-angle directly over the polar axis. It is now quite easy to move the telescope in declination while looking through the finder with the hand on the corner of the cube only two and a half feet from the center of the declination axis produced. With a centrally hung refractor-tube of the same weight and an available leverage of fifteen to eighteen feet, the very slight effort required to move the tube might even be a disadvantage. The responsiveness of the declination slow motion has likewise greatly improved.

The Cassegrainian system of the 37-inch Mills reflector has from the beginning been subject to progressive focal changes in the first half of the night. These changes were always in the direction of increasing focal length, it being necessary gradually and continuously to increase the focal length of the telescope during the first four or five hours of the night by amounts which reach totals of fifteen to twenty-five millimeters. It was decided to try artificial cooling of the mirror, in the hope that by reducing in advance the mirror temperature to that of the night these progressive focal changes might be greatly reduced or destroyed entirely.

As a preliminary to the testing of the refrigeration the ventilation of the mirror in its cell was bettered. The great mirror has a clear aperture of 36.56 inches, is 5.5 inches thick at the center, and is pierced by a central hole 4.87 inches in

diameter. The cast-iron cell is about one half inch in thickness; at the center of the back is a hole 8.5 inches in diameter, which was formerly generally kept closed with a cast-iron filler disk having a two-inch aperture for the passage of the light to the spectrograph slit. Aside from this aperture, and a few small ones for the adjusting screws of the mirror supports, the only other ventilating opening in the ironwork about the mirror was a small window six inches square cut in one side of the cube just above the mirror. The mirror cover, which had formerly rested nearly in contact with the mirror, was moved fourteen inches up the cube; the cube window was enlarged to six by sixteen inches and a similar window cut on the opposite side of the cube. Six holes, each 5.2 inches in diameter, were cut in the iron back of the cell, and the use of the filler-plate discontinued. The ventilating area at the back of the mirror is thus now about one sixth of the area of the mirror.

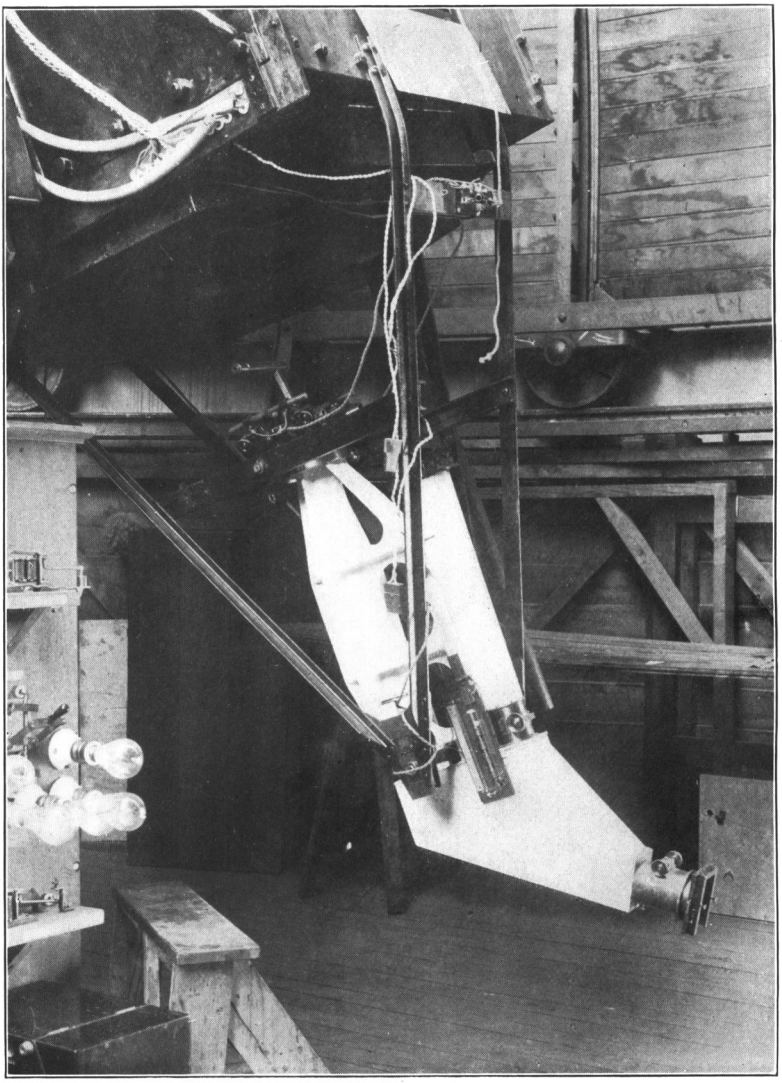
During the past observing season record has been kept of the focal changes, and as a result of the study of these, in connection with the temperature variations, the following general conclusions have been drawn with reference to the behavior of the mirror system without artificial cooling:—

(1) The increased ventilation about the mirror has only slightly reduced the focal range in the first part of the night, the average under normal summer observing conditions being about fourteen millimeters. A position of focal equilibrium is probably reached somewhat earlier, all focal change ceasing as a rule by four hours after sunset.

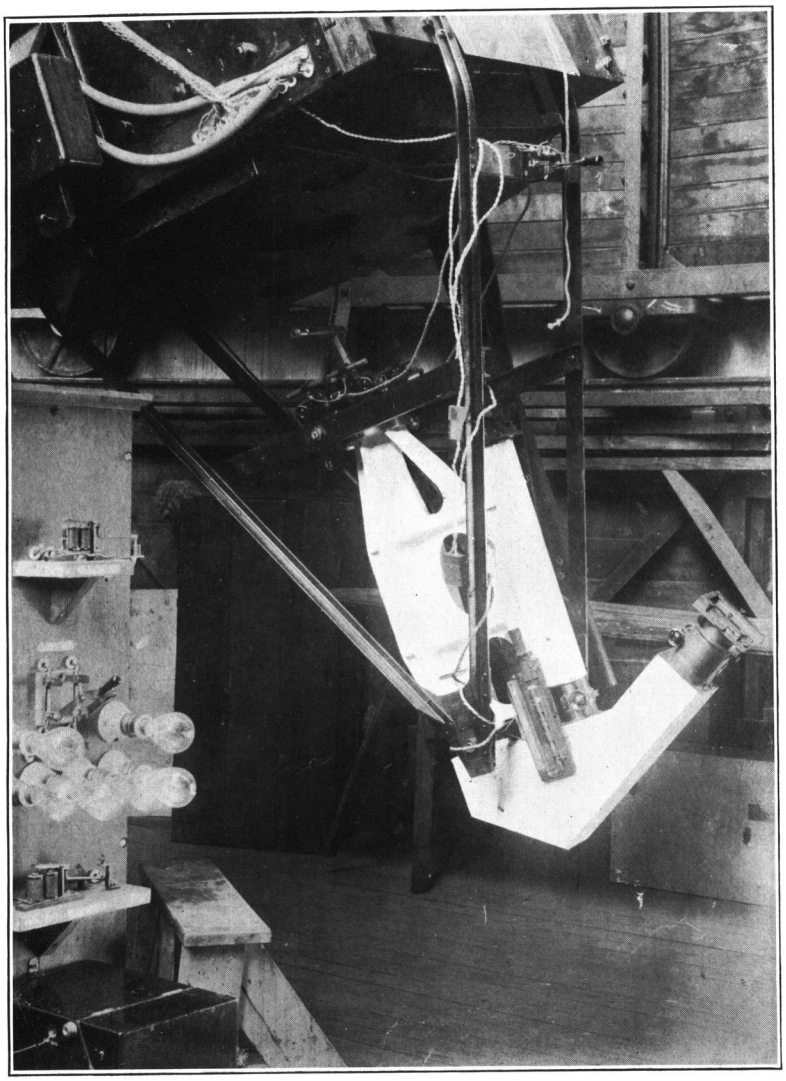
(2) Silvering the back of the mirror, as recommended by Professors WADSWORTH and RITCHEY, has had no appreciable effect in reducing the focal range. Insulating the sides of the hole in the primary mirror with blanketing has also been without effect.

(3) The focus of the system after equilibrium is reached seems not to vary noticeably for different temperatures.

(4) The focal changes have their origin in the large mirror, and not in the secondary; this has been shown by tests on a number of nights by star-trails on an inclined photographic plate at the focus of the primary. These showed a progressive lengthening of the focus of the main mirror by amounts ranging from 1.2^{mm} to 2.2^{mm}. As a focal change in the



THE ONE-PRISM SPECTROGRAPH.



THE TWO-PRISM SPECTROGRAPH.

primary produces 10.1 times as much change in the focus of the entire system, these results are seen to be in good accord with the ranges secured for the system as a whole. Similar tests on two evenings exposing alternately the inner and outer portions of the primary showed that the outer ring was about 1.2^{mm} shorter focally than the inner zone, a difference which vanished in similar tests made in the morning hours.

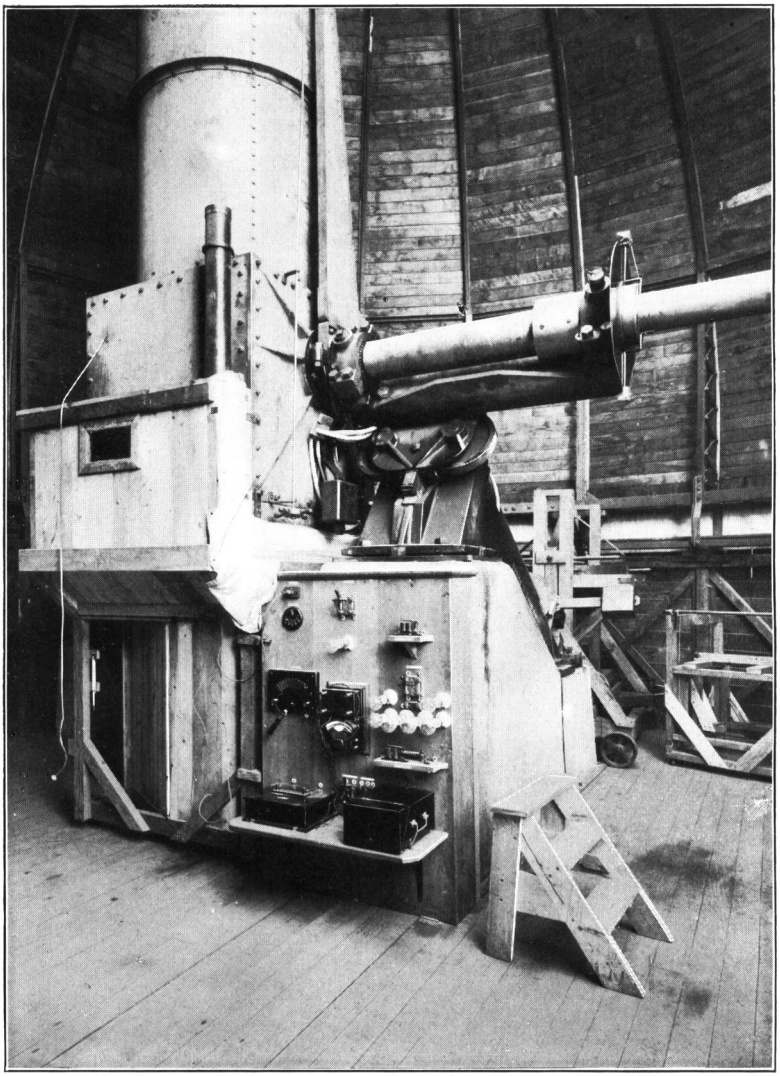
(5) The relation connecting the focal changes of the mirror with the fall in external temperature is apparently a very complex one, many factors entering in. Frequently a drop of 2° C. between the temperatures of afternoon and early evening will cause as great a focal range as a drop of 6° C. In general, the rapidity with which a temperature change takes place seems to be of greater effect than its absolute magnitude.

The system of refrigeration employed is the direct anhydrous ammonia method. The machine is the smallest of the regular commercial sizes of isolated cooling plants manufactured by the Brunswick Refrigerating Company, of Brunswick, N. J. It requires one horsepower to run it and the pump used for water circulation, and is rated by the manufacturers as having a capacity equal to that of the melting of one hundred pounds of ice per day. It is located in the shop forty-eight feet from the telescope pier, to one side of which are attached the cooling coils, three feet by two feet by six inches, of one-inch piping, and well insulated from the pier. The coils are connected with the ammonia machine by a double line of piping of one-fourth-inch bore, insulated with cork and felt. In use a removable wooden case lined with thick felt is rolled into position about the telescope; this case contains about eighty-five cubic feet and insulates from the outside air the spectrograph, mirror, and lower half of the cube. Two electric fans keep the air in the case in constant circulation. The refrigerating machine is entirely automatic in its action, and no difficulty is found in reducing the temperature within the case by 5° or 6° C. in a run of one hour and a half. After some experiments, the following procedure has been found most advantageous. Refrigeration is started about three hours before sunset and the temperature at the mirror reduced about 5° C. The case is removed from the telescope about forty minutes before sunset; at this time the outside temperature is falling rapidly, and the mirror, at least in its outer

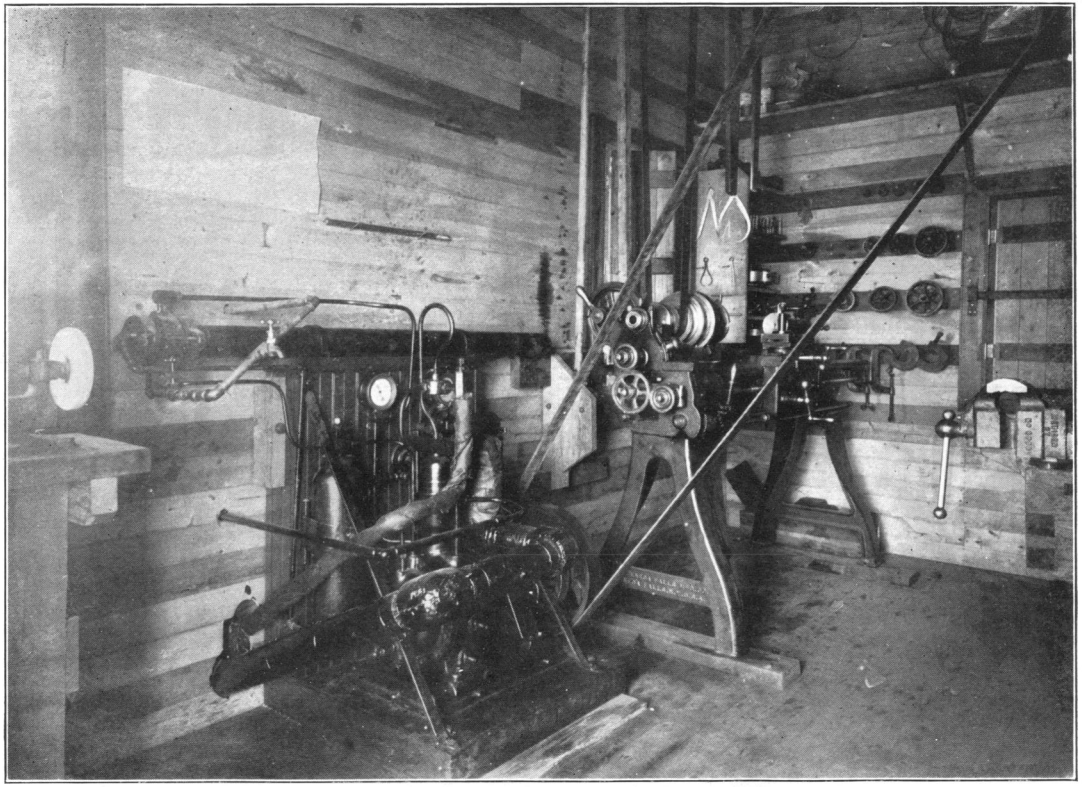
portions, is colder than the air. Equilibrium is reached by sunset, or very shortly after, when focal tests almost invariably show the same value of the focus as that at which it had been left at the time of closing work on the night before. Focal changes are either entirely absent or small, being rarely greater than five millimeters. Sudden changes in the night temperature still produce focal changes of small amount. Fortunately the average temperature gradient during normal summer nights on Cerro San Cristobal is very regular; on quite a proportion of nights when cooling has been used there has been no focal change during the entire night.

The change in the source of electric power rendered necessary the complete rewiring of the observatory, and use was made of this opportunity to arrange all the circuits used in the spectroscopic work in a switchboard on the front of the pier. To this switchboard come, underneath the floor of the dome, a circuit from three primary cells used with the relay for the heating of the spectrograph case; a circuit from four storage-batteries, held in reserve for the spark and used at present only for small lights to illuminate the divided circles; and the 220-volt circuit, used for heating the temperature case, for lights and for the arc comparison. Arc-comparison apparatus has lately been attached to the spectrograph, though the spark is held in readiness for special work; for this latter the condenser and self-induction can be cut in or out by switches. All the electrical circuits, including the high tension for the spark, are carried up over the axes of the telescope to a line of binding-posts near the mirror cell, to which flexible cord and convenient plugs are fitted, doing away with all use of binding-posts in actual work.

A one-prism and a two-prism spectrograph have been added to the equipment. These are arranged to attach to the steel frame of the three-prism instrument by removing the box containing the three-prism train. They use the collimator, slit, comparison apparatus, and supporting truss of the three-prism instrument. The prism-boxes and camera-tubes of the new spectrographs are built up of strong brass plates, the general scheme of construction being that employed in the remounted Mills spectrograph at Lick Observatory. Tests have failed to show any flexure effects. The new camera-lenses are of the Hartmann uncemented type, consisting of



THE REFRIGERATING CASE IN POSITION.



THE REFRIGERATING MACHINE, IN THE WORHSHOP.

three lenses with intervening air-spaces; the total thickness of glass traversed by the beam at the center of the lenses is 0.92 inch. The focal length of the camera for the two-prism instrument is sixteen inches, that for the one-prism eighteen inches. A special temperature-case fits either of the two new instruments. The heating arrangement is similar to that of the three-prism spectrograph, a mercurial thermostat on the steel body truss serving for all three instruments. It is Director CAMPBELL'S intention that radial-velocity determinations in the southern sky shall be carried down to fainter stars with the new instruments, but owing to the long delay in gaining possession of the lenses due to the congestion of business at Valparaiso following the great earthquake, no systematic work has yet been undertaken.

Among minor additions to the equipment may be mentioned a new Toepfer measuring-engine and a Berolina calculating-machine. A photographic attachment has been fitted up to test the performance of the telescope in direct photography of clusters and nebulæ.

The resilvering of the mirror has been expedited by the building of a heavy wooden frame on wheels to withdraw the mirror and cell, and to support the mirror during the process of silvering. A convenient carriage has also been built to remove the spectrograph from the telescope. A card catalogue has been made to keep record of the results of the work; this is on the same plan as that used at Lick Observatory for the results from the northern sky.

Mr. MILLS'S generosity in providing this increased equipment for the work of the next five years will add greatly to the comfort of the observers and the ease of manipulation of the instruments, besides materially enlarging the scope and quantity of the work. The present equipment, with spectrographs of one, two, and three prisms, may be considered quite complete for general work in stellar spectroscopy and determinations of stellar velocities, and will render the velocity survey of the stars of the southern heavens much more complete and comprehensive, a result of great moment in improving our knowledge of the Sun's motion through space, and of the structure of our stellar universe.

THE D. O. MILLS EXPEDITION,
Santiago, Chile, June, 1907.